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(54) **Integrated optical waveguide and method of manufacturing**

Integriert-optischer Wellenleiter und Verfahren zu seiner Herstellung

Guide d'onde optique intégré et procédé de fabrication d'un tel guide

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- **SUZUKI SET AL: "POLARISATION-INSENSITIVE ARRAYED-WAVEGUIDE GRATINGS USING DOPANT- RICH SILICA-BASED GLASS WITH THERMAL EXPANSION ADJUSTED TO SI SUBSTRATE" ELECTRONICS LETTERS, GB, IEE STEVENAGE**, vol. 33, no. 13, 19 June 1997 (1997-06-19), pages 1173-1174, XP000734144 ISSN: 0013-5194
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Description

BACKGROUND OF THE INVENTION

[0001] The present invention relates to an integrated optical waveguide and a method for manufacturing the same.

[0002] Communication systems utilising optical systems having become common place recently. When first introduced, the optical systems were based on the use of optical fibers which were symmetrically round. More recently however, integrated waveguide devices have been introduced due to the ease with which different types of device can be formed utilising techniques learned from semiconductor manufacture. However, integrated waveguides frequently exhibit differing refractive indices parallel and perpendicular to the plane of the surface of the substrate. Unpolarised light, which enters a birefringent integrated waveguide is split into one component in a direction parallel to and one component in a direction perpendicular to the surface of the substrate of the waveguide and these components propagate at different rates. This makes optical circuits more difficult to design because wavelength - selective elements such as directional couplers or wavelength multiplexers incorporating reflection gratings can be optimally designed for only one polarization direction. This phenomenon is termed by birefringence and in the case of crystalline planar substrates, the birefringence results from the crystalline structure and the selected orientation of the crystals to the plane. Amorphous, transparent materials such as glass do not exhibit birefringence provided they are stress free.

[0003] Much attention has therefore been directed to producing low-birefringence integrated optical waveguides and the technique normally employed is to manufacture the waveguides from glass on a essentially planar silicon crystal substrate. With this method, the layers of glass are produced at elevated temperature and/or require high temperature treatment in order to ensure homogeneity. The result of the high temperature treatment is that the difference between the thermal expansion co-efficient of the substrate and the layers coated thereon therein leads to considerable stresses on cooling and, in the event of single-sided coating, even to bending of the silicon crystal substrate. Owing to the well known stress-optical effect, these stresses bring about birefringence in the light carrying core of the waveguide. The effect of the birefringence is shown in Fig. 3 where the peak insertion losses in all TE and TM modes occur at different wavelengths.

[0004] A number of different proposals have been made to overcome this problem and while some techniques are capable of achieving very low polarisation sensitivity (less than or equal to 0.05 nm for arrayed waveguide demultiplexers) they are not suitable for low cost/high volume production. DE-A-4433738 discloses a technique which is stated to result in low-birefringence

and involves making the thermal coefficient of expansion of the optical core material the same as the temperature coefficient of expansion of the silicon substrate. This document is alleged to result in a reduction in the polarisation sensitivity in the region of 0.1 to 0.2 nm which is still not sufficiently good for practical purposes.

SUMMARY OF THE INVENTION

[0005] It is an object of the present invention to provide an integrated optical waveguide device which exhibits low birefringence ie low polarisation sensitivity of the order of 0.05 nm.

[0006] The present invention provides an integrated optical waveguide comprising at least two cladding layers on a substrate and at least one core layer disposed between the cladding layers, said core layer having a higher refractive index than the refractive index of the cladding layers, wherein the material of the overcladding layer has a thermal coefficient of expansion substantially matched with that of the material of the substrate, which thermal coefficient of expansion is not matched with that of the material of the core layer.

[0007] The present invention also provides a method of manufacturing such an integrated optical waveguide. Preferably, the overcladding is doped with boron and phosphorous containing material in order to produce the desired thermal coefficient of expansion in the overcladding layer.

[0008] We have found that the thermal coefficient of expansion of the undercladding and of the optical core material can vary widely from between 10 and $30 \times 10^{-7} \text{ }^{\circ}\text{C}^{-1}$ and the device will still exhibit low birefringence.

BRIEF DESCRIPTION OF THE DRAWINGS

[0009] In order that the present invention be more readily understood, an embodiment thereof will now be described by way of example only with reference to the accompanying drawings, in which:-

Fig. 1 shows a cross sectional side view of a waveguide device according to the present invention;

Fig. 2 shows diagrammatically an arrayed grating wavelength demultiplexer;

Fig. 3 shows a diagram of insertion loss against wavelength for both the TE and TM modes;

Fig. 4 shows a diagram of insertion loss against wavelength for both the TE and TM modes for a device according to the present invention; and

Fig. 5 shows a diagram of insertion loss against wavelength for the TE mode of a 16 channel device according to the present invention.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

[0010] An integrated optical waveguide device as shown in Fig. 1 comprises a substrate 1 usually in the form of a single silicon crystal on which a cladding layer 2 is formed on one side. The layer 2 usually contains silicon dioxide (SiO_2) and may be thermally grown or deposited by a process such as PECVD, LPCVD, APCVD or FHD.

[0011] The layer 2 is normally more than $10\mu\text{m}$ in thickness and is consolidated by annealing at temperatures above 1100°C . One or more optical core elements are formed in a layer 3. Once more the layer 3 contains SiO_2 but the refractive index of the layer 3 is higher than the refractive index of the layer 2. Typically the difference in refractive index is of the order of 5 to 20×10^{-3} and is obtained by doping the core layer with germania, phosphorous oxide, boron oxide, or combinations thereof. Thereafter, an overcladding layer 4 is provided which will be seen to cover three sides of the optical core layer 3. The overcladding layer 4 has the same refractive index as the undercladding layer 2 and is formed using any of the techniques mentioned in relation to the undercladding layer 2.

[0012] The above structure is basically conventional but the present invention differs from the conventional structure insofar as the overcladding layer 4 is doped with a suitable material so as to achieve a thermal coefficient of expansion which is very close to the thermal coefficient of expansion of the substrate 1. How the doping material is chosen and how the quantity of doping is determined will now be described.

[0013] It is known that doping silicon oxide with a dopant such as boron oxide and phosphorous oxide will increase the thermal coefficient of expansion of the material so doped. It is also known that the stress in a layer is related to the thickness T of the layer and the thickness D , module of elasticity E and Poisson coefficient V of the substrate by the equation $\sigma = E \cdot D^2 / [6(1-v) \cdot R \cdot T]$

where R is the measured curvature of the combination. Using the stress-optical coefficient K , the birefringence B can be obtained since

$B = K \cdot \sigma = n_{\text{TE}} - n_{\text{TM}}$ where n_{TE} is the refractive index of the TE mode and n_{TM} is a refractive index for the TM mode of the optical core. It is known that the stress-optical coefficient K is approximately 3.5 nm/cm/bar for SiO_2 .

[0014] On the basis of this background information, a test device having the basic structure shown in Fig. 1 was prepared and tested in the configuration shown in Fig. 2. The curvature R of the overcladding was measured using a profilometer. An overcladding layer of thickness $15\mu\text{m}$ was used. The amount of doping and the dopant material were changed in successive experiments until the measured curvature indicated that birefringence was reduced to a minimum. It was found on analysis from a satisfactory test that the thermal coefficient

of expansion of the overcladding layer for low birefringence was of the same order as the thermal coefficient of expansion of the substrate 1; in other words of the order of $35 \times 10^{-7} ^\circ\text{C}^{-1}$. Preferably, the doped overcladding layer should be in a state of low compressive stress compared to the substrate, in order to avoid stress cracking due to defects.

[0015] The test also showed that an overcladding layer 4 having a thermal coefficient of expansion of around $28 \times 10^{-7} ^\circ\text{C}^{-1}$ gave a wavelength shift due to polarisation of the order 0.2 to 0.25 nm which is deemed not satisfactory for practical devices. This is shown in Fig. 3. It was also found that doping the undercladding layer 2 with boron or phosphorous material to produce a thermal coefficient of expansion of the order of $22 \times 10^{-7} ^\circ\text{C}^{-1}$ and doping of the core layer 3 with boron phosphorous or germanium containing material to produce thermal coefficients of expansion varying from 13 to $30 \times 10^{-7} ^\circ\text{C}^{-1}$ showed that without the correct doping of the overcladding 4 to match the thermal coefficient of expansion of the substrate, it was not possible to achieve polarisation sensitivity below 0.1 nm .

[0016] The results of the test were then noted and practical devices produced using the same starting materials as the test but by doping the overcladding layer 4 with the appropriate amount of dopant to produce a thermal coefficient of expansion of the order $35 \times 10^{-7} ^\circ\text{C}^{-1}$ which is close to that of the silicon substrate. The effect in the graphs of insertion loss for the TE and TM modes as a function of wavelength is shown in Fig. 4.

[0017] Further tests have shown that a thermal coefficient of expansion of $33.8 \times 10^{-7} ^\circ\text{C}^{-1}$ gave satisfactory results as did $37.3 \times 10^{-7} ^\circ\text{C}^{-1}$. It is considered advisable to keep the thermal coefficient of expansion of the overcladding layer 4 to be less than or equal to that of the substrate 1 so that the layer 4 stays in a state of compressive stress.

[0018] The benefits of this invention are that 16 channel wavelength demultiplexors can be produced which have insertion losses as shown in Fig. 5. The graphs of insertion loss in this figure are true for both the TE and TM modes.

Claims

1. An integrated optical waveguide comprising at least two cladding layers (2,4) on a substrate (1) and at least one core layer (3) disposed between the cladding layers, said core layer (3) having a higher refractive index than the refractive index of the cladding layers, wherein the material of the overcladding layer (4) has a thermal coefficient of expansion substantially matched with that of the material of the substrate (1), which thermal coefficient of expansion is not matched with that of the material of the core layer (3).

2. A process for fabricating an integrated optical waveguide comprising forming an undercladding layer (2) on a major surface of a substrate (1), forming a waveguide core (3) on the undercladding layer (2), said core having a higher refractive index than the refractive index of the undercladding layer (2), and forming an overcladding layer (4), wherein the material of the overcladding layer (4), is doped in order to produce a thermal coefficient of expansion substantially matched with that of the material of the substrate (1), which thermal coefficient of expansion is not matched with that of the material of the core layer (3).

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3. A process according to claim 2, wherein the substrate is formed of silicon and the layers are provided thereon contain silicon oxide.

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4. A process according to claim 3, wherein the overcladding layer (4) is doped with material containing germanium, boron and/or phosphorous.

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5. A process according to claim 2, wherein the undercladding layer is doped with material containing germanium, boron and/or phosphorous.

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6. A process according to claim 2, wherein each of the layers is formed by a process such as PECVD, LPCVD, APCVD or FHD.

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7. A process according to claim 2, wherein the thermal coefficient of expansion of the overcladding layer is substantially equal to but no greater than that of the substrate.

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8. A process according to claim 7, wherein the substrate is formed of silicon and the thermal coefficient of expansion of the overcladding layer is in the range $30 \text{ to } 35 \times 10^{-7} \text{ }^{\circ}\text{C}^{-1}$.

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zug-Schicht (2) auf einer Hauptfläche eines Substrates (1), die Bildung eines Wellenleiter-Kerns (3) auf der unteren Überzug-Schicht (2), wobei der Kern einen höheren Brechungsindex als der Brechungsindex der unteren Überzug-Schicht (2) aufweist, und die Bildung einer oberen Überzug-Schicht (4) umfasst, wobei das Material der oberen Überzug-Schicht (4) dotiert ist, um einen thermischen Ausdehnungskoeffizienten zu erzeugen, der im Wesentlichen an den des Materials des Substrates (1) angepasst ist, wobei dieser thermische Ausdehnungskoeffizient nicht an den des Materials der Kernschicht (3) angepasst ist.

3. Verfahren nach Anspruch 2, bei dem das Substrat aus Silizium gebildet ist und die darauf angeordneten Schichten Siliziumdioxid enthalten.

4. Verfahren nach Anspruch 3, bei dem die obere Überzug-Schicht (4) mit einem Material dotiert ist, das Germanium, Bor und/oder Phosphor enthält.

5. Verfahren nach Anspruch 2, bei dem die untere Überzug-Schicht mit einem Material dotiert ist, das Germanium, Bor und/oder Phosphor enthält.

6. Verfahren nach Anspruch 2, bei dem jede der Schichten durch einen Prozess, wie z. B. PECVD, LPCVD, APCVD oder FHD gebildet ist.

7. Verfahren nach Anspruch 2, bei dem der thermische Ausdehnungskoeffizient der oberen Überzug-Schicht im Wesentlichen gleich, jedoch nicht größer als der des Substrates ist.

8. Verfahren nach Anspruch 7, bei dem das Substrat aus Silizium gebildet ist und der thermische Ausdehnungskoeffizient der oberen Überzug-Schicht in dem Bereich von $30\text{-}35 \times 10^{-7} \text{ }^{\circ}\text{C}^{-1}$ liegt.

Patentansprüche

1. Integrierter Lichtwellenleiter mit zumindest zwei Überzug-Schichten (2, 4) auf einem Substrat (1) und zumindest einer Kernschicht (3), die zwischen den Überzug-Schichten angeordnet ist, wobei die Kernschicht (3) einen höheren Brechungsindex als der Brechungsindex der Überzug-Schichten hat, wobei das Material der oberen Überzug-Schicht (4) einen thermischen Ausdehnungskoeffizienten aufweist, der im Wesentlichen an den des Materials des Substrats (1) angepasst ist, wobei dieser thermische Ausdehnungskoeffizient nicht an den des Materials der Kernschicht (3) angepasst ist.
2. Verfahren zur Herstellung eines integrierten Lichtwellenleiters, das die Bildung einer unteren Über-

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Revendications

1. Guide d'onde optique intégré comprenant au moins deux couches de gaine (2, 4) sur un substrat (1) et au moins une couche de coeur (3) disposée entre les couches de gaine, ladite couche de coeur (3) ayant un indice de réfraction supérieur à l'indice de réfraction des couches de gaine, dans lequel la matière de la couche de gaine sus-jacente (4) a un coefficient de dilatation thermique sensiblement harmonisé avec celui de la matière du substrat (1), lequel coefficient de dilatation thermique n'est pas harmonisé avec celui de la matière de la couche de coeur (3).
2. Procédé de fabrication d'un guide d'onde optique intégré comprenant les étapes consistant à former

une couche de gaine sous-jacente (2) sur une surface principale d'un substrat (1), former un coeur de guide d'onde (3) sur la couche de gaine sous-jacente (2), ledit coeur ayant un indice de réfraction supérieur à l'indice de réfraction de la couche de gaine sous-jacente (2), et former une couche de gaine sus-jacente (4), dans lequel la matière de la couche de gaine sus-jacente (4) est dopée afin d'obtenir un coefficient de dilatation thermique sensiblement harmonisé avec celui de la matière du substrat (1), lequel coefficient de dilatation thermique n'est pas harmonisé avec celui de la matière de la couche de coeur (3).

3. Procédé selon la revendication 2, dans lequel le substrat est réalisé en silicium et les couches placées sur celui-ci contiennent de l'oxyde de silicium. 15
4. Procédé selon la revendication 3, dans lequel la couche de gaine sus-jacente (4) est dopée avec une matière contenant du germanium, du bore et/ou du phosphore. 20
5. Procédé selon la revendication 2, dans lequel la couche de gaine sous-jacente (2) est dopée avec une matière contenant du germanium, du bore et/ou du phosphore. 25
6. Procédé selon la revendication 2, dans lequel chacune des couches est formée selon un procédé tel que le PECVD (dépôt chimique en phase vapeur activé par plasma), le LPCVD (dépôt chimique en phase vapeur sous pression réduite), l'APCVD (dépôt chimique en phase vapeur à pression ambiante) ou le FHD (dépôt hydrolyse à la flamme). 30 35
7. Procédé selon la revendication 2, dans lequel le coefficient de dilatation thermique de la couche de gaine sus-jacente est sensiblement égal mais pas supérieur à celui du substrat. 40
8. Procédé selon la revendication 7, dans lequel le substrat est réalisé en silicium et le coefficient de dilatation thermique de la couche de gaine sus-jacente varie de 30 à $35 \times 10^{-7} \times ^\circ\text{C}^{-1}$. 45

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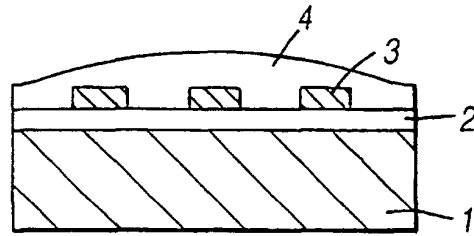


Fig.1

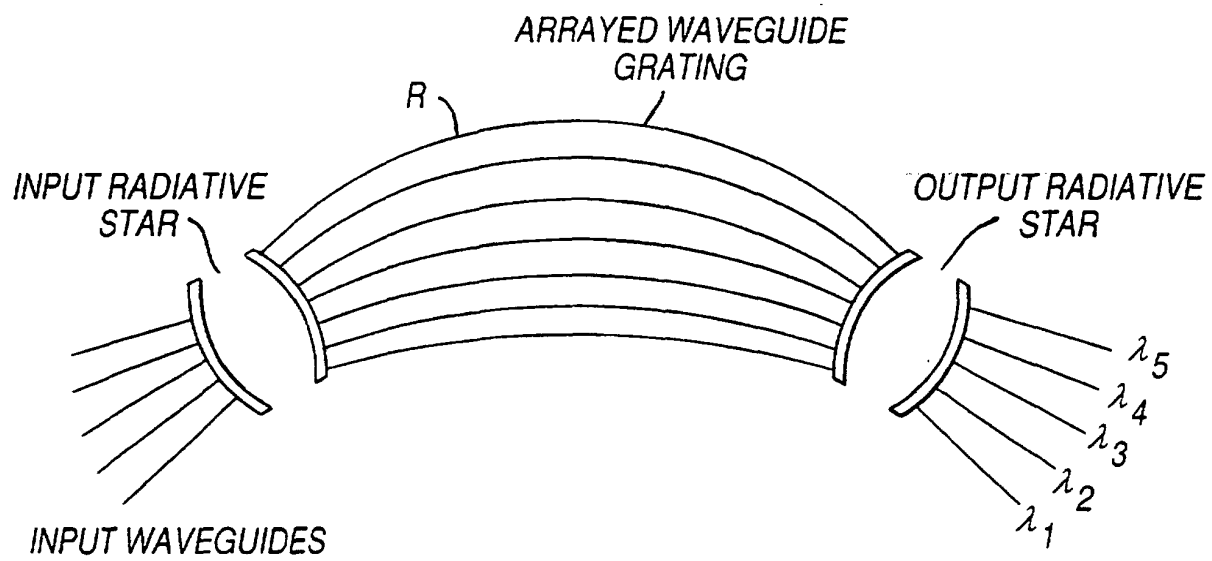


Fig.2

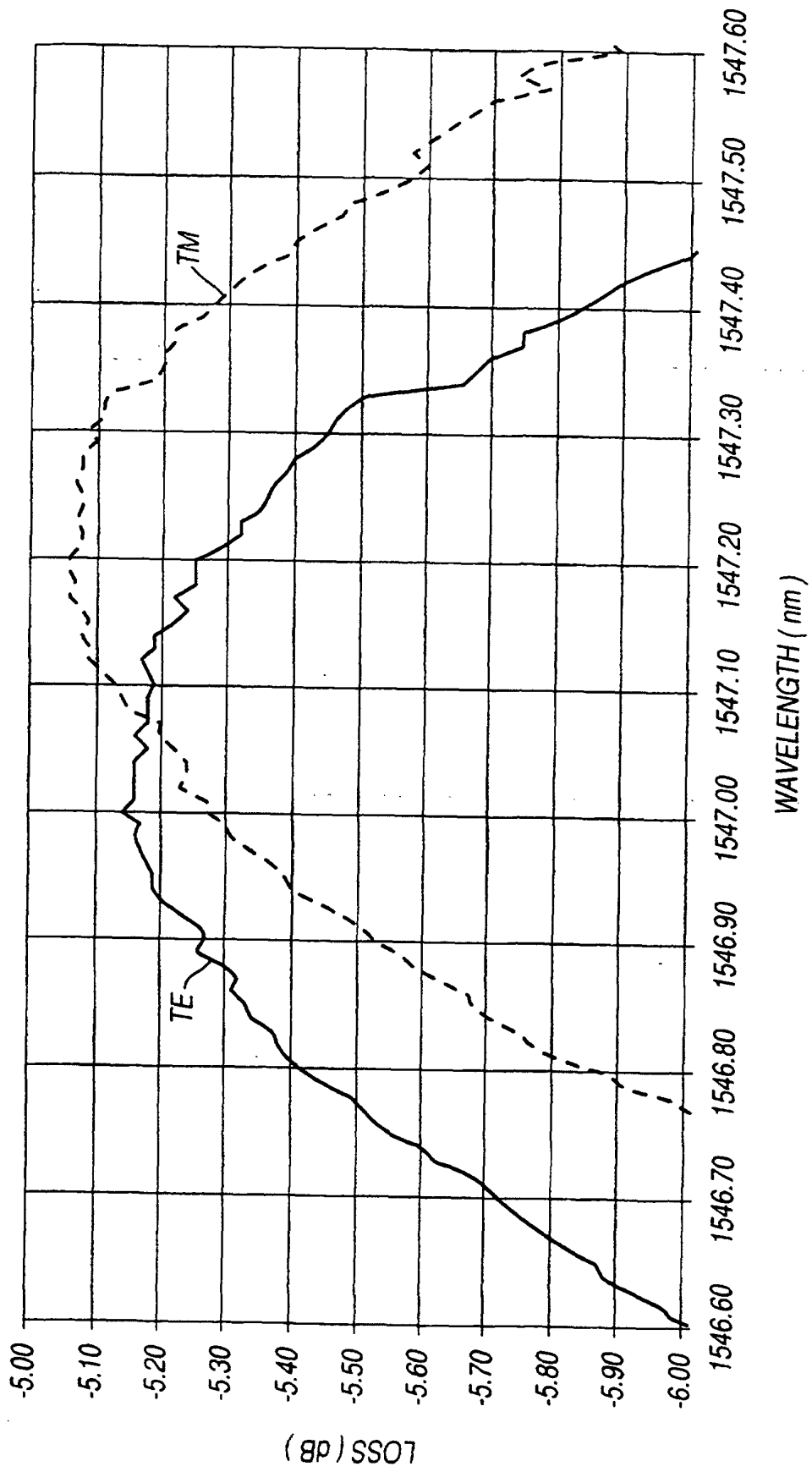


Fig.3

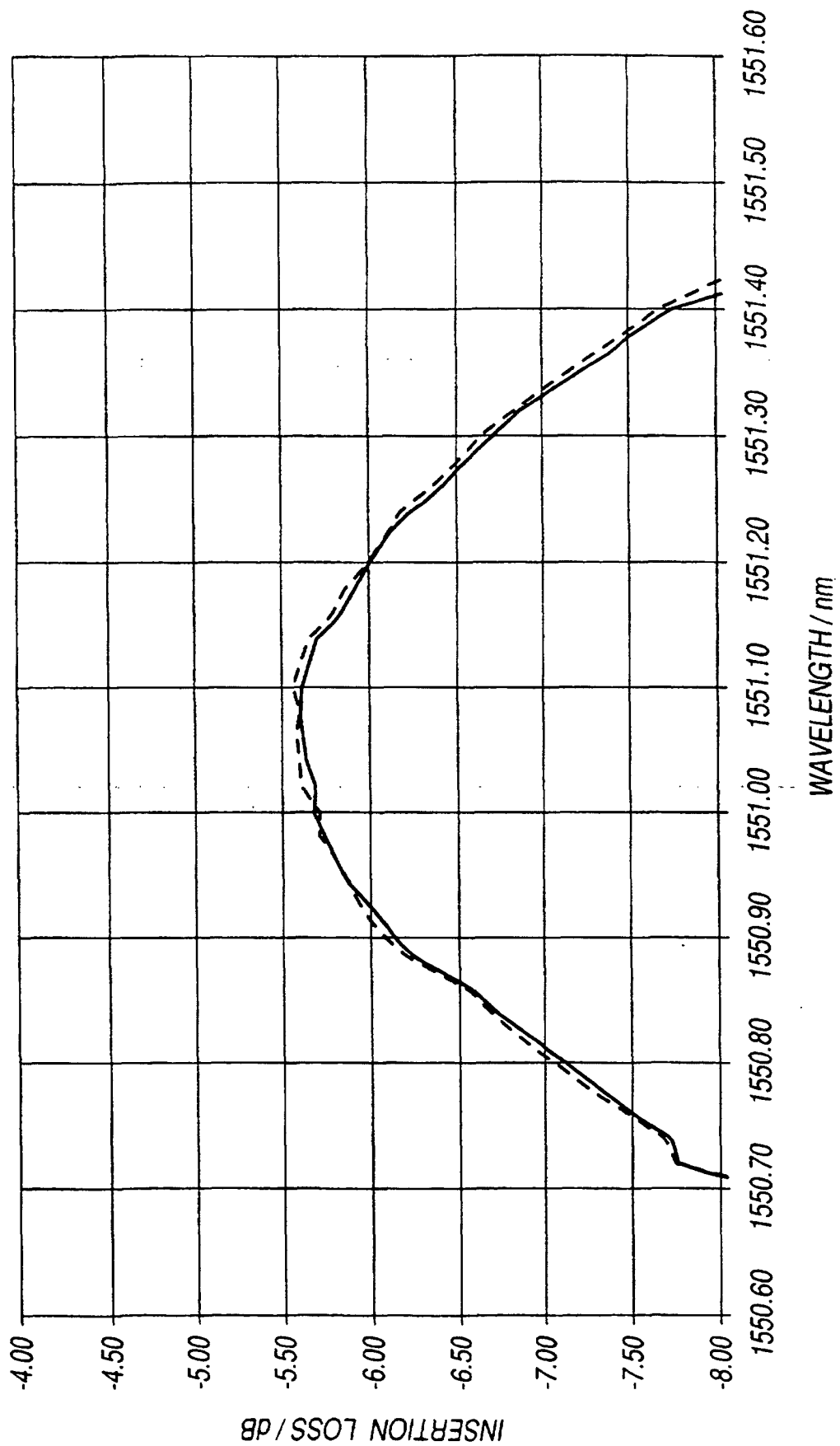


Fig.4

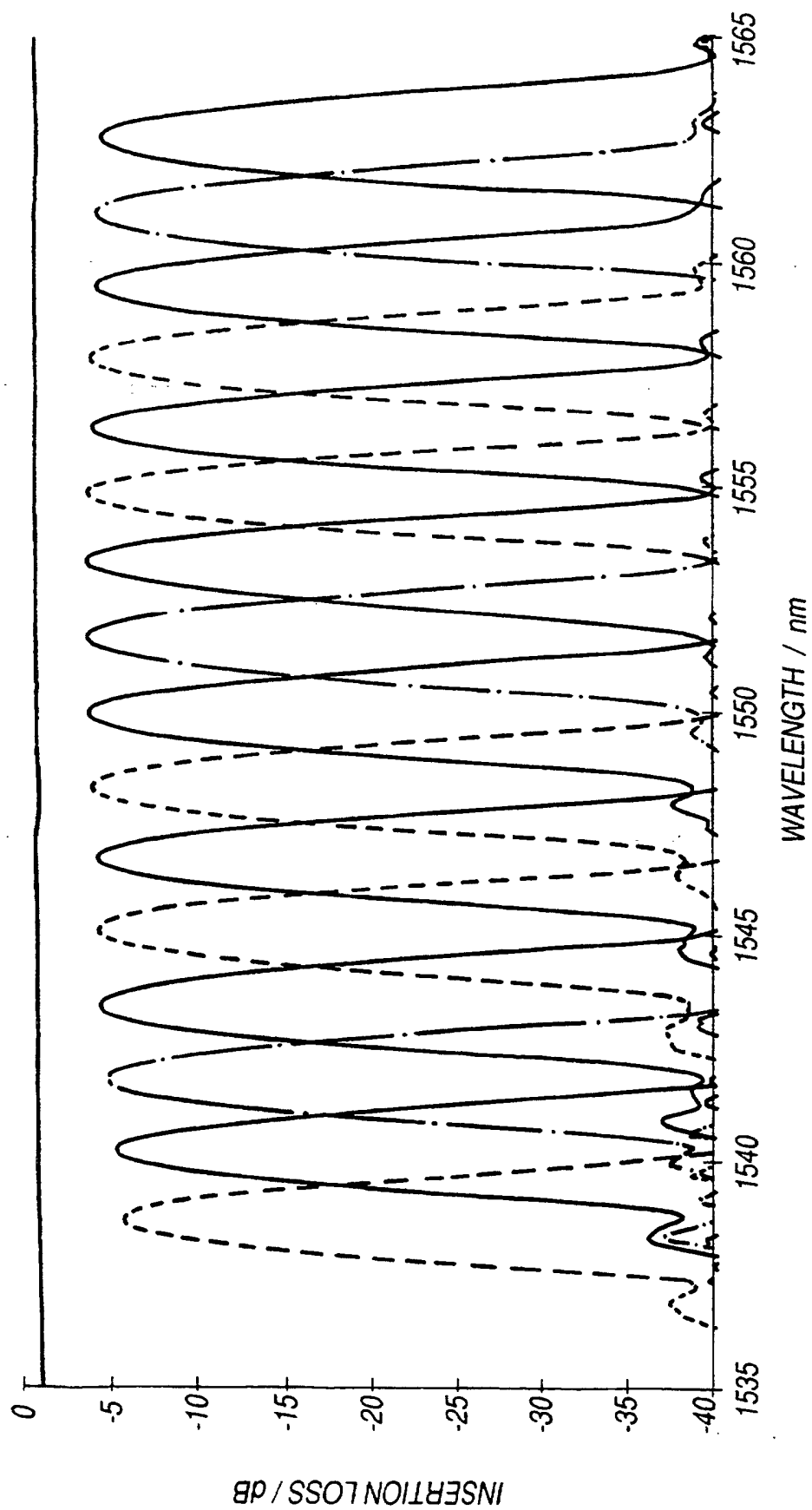


Fig.5